

## Upland rice response to potassium fertilization on a Brazilian oxisol<sup>1</sup>

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### Abstract

Even though K is an essential nutrient, the response of upland rice to K fertilization under field conditions has not been adequately documented. This research was conducted to examine the influence of K fertilization on yield of upland rice (*Oryza sativa* L.). In the first three years, K was broadcast at rates of 0, 42, 84, 126 and 168 kg K ha<sup>-1</sup>. In the last two years K was banded at rates of 0, 25, 50, 75 and 100 kg K ha<sup>-1</sup>. The experiment was conducted on an Oxisol (Typic Haplustox) during five consecutive years. Potassium significantly increased grain yields and dry matter production but response varied from cultivar to cultivar and year to year. Drought and panicle neck blast played an important role in limiting upland rice yield response to K fertilization. Potassium application rates associated with maximum grain yield varied from 83 to 127 kg K ha<sup>-1</sup> when K was broadcast and from 47 to 67 kg K ha<sup>-1</sup> when K was banded. Previous broadcast K, favorable weather and blast resistant cultivars probably contributed to higher yields with K banding in the fourth and fifth growing seasons.

### Introduction

Upland rice accounts for 74% of the 8.2 million hectares of rice grown in Latin America [3]. The savannas of Colombia, Venezuela, Bolivia, and Guyana, the Cerrado region of Brazil and other areas constitute an important potential resource for the production of crops such as rice. Most of the soils of these areas are Oxisols, Ultisols, or Inceptisols. These soils are generally characterized by extreme acidity and low levels of available nutrients [5, 6, 9]. Deficiencies of N, P, K, Ca, S, Mg and Zn are very common in Oxisol-Ultisol regions of Latin America. Aluminum and Mn toxicities are also common in these soils [9].

Long-term fertilizer experiments are essential to provide information on the relationship between crop yields and fertilizer application rates. This information is needed for estimating optimal ap-

plications rates of fertilizer for a particular soil and region. Long-term experiments reflect not only the crop response to fertilizer but also the soil fertility balance for a given cropping system. Several authors [2, 8] have provided important information in this regard.

The response of upland rice to K fertilization under field conditions has not been adequately documented. The objectives of this study were: 1) to determine upland rice response to K fertilization; 2) to evaluate cultivar differences in response to K fertilization; 3) to evaluate broadcast vs. band application of K; and 4) to determine the effect of K application on distribution of K in the soil profile.

### Materials and methods

A field experiment was conducted during five

Table 1. Fertilizer and lime application during five consecutive years

Nutrient or Lime	1st crop <sup>a</sup>	2nd crop <sup>a</sup>	3rd crop <sup>a</sup>	4th crop <sup>b</sup>	5th crop <sup>b</sup>
N kg ha <sup>-1</sup>	50	50	50	50	50
P kg ha <sup>-1</sup>	44	44	88	44	44
Micronutrients kg ha <sup>-1</sup>	5Zn	5Zn	5Zn + 40FTE-BR-12	40FTE-BR-12	40-FTE-Br-12
Dolomitic Lime t ha <sup>-1</sup>	2	3	3	3	0
K levels kg ha <sup>-1</sup>	0	0	0	0	0
	42	42	42	25	25
	84	84	84	50	50
	126	126	126	75	75
	168	168	168	100	100

N was applied as (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>, P as triple superphosphate, K as KCl, and micronutrients as ZnSO<sub>4</sub> and fritted glass material (FTE-BR-12).

<sup>a</sup> Broadcast application of K.

<sup>b</sup> Band application of K.

consecutive years at the EMBRAPA – National Rice and Bean Research Center's Experimental Station Capivara – Goiania, Brazil. The soil at the experimental site was classified as a Dark Red Latosol in the Brazilian system and as a clayey, kaolinitic, isothermic Typic Haplustox in Soil Taxonomy. The soil had the following chemical properties: pH, 5.1; extractable P, 0.6 mg kg<sup>-1</sup>; extractable K, 46 mg kg<sup>-1</sup>; extractable Ca, 120 mg kg<sup>-1</sup>; extractable Mg, 36 mg kg<sup>-1</sup>; and extractable Al 36 mg kg<sup>-1</sup>. Phosphorus and K were extracted by the Mehlich 1 extracting solution (0.05 M HCl + 0.0125 M H<sub>2</sub>SO<sub>4</sub>). Phosphorus was determined colorimetrically [1] and K by flame photometry. Aluminum, Ca and Mg were extracted with 1 M KCl. Aluminum was determined by titration with NaOH [10] and Ca and Mg by titration with EDTA [7].

Quantities of fertilizer and lime applied in the five cropping seasons are presented in Table 1. In the first three years, all fertilizers were broadcast at the time of planting and incorporated with a roto tiller. In the last two croppings, all fertilizers were banded.

The treatments consisted of a factorial arrangement of cultivars and K levels. The upland rice cultivars, Dourado Precoce, IAC 47 and IAC 164, were used the initial four years of the study. Blast resistant cultivars (CNA 4166, CNA 4476 and CNA 418) were used in the fifth year of cropping. Potassium was broadcast at application rates of 0, 42, 84, 126 and 168 kg K ha<sup>-1</sup> the first three years and banded at rates of 0, 25, 50, 75 and 100 kg K ha<sup>-1</sup> in the last two years. A split-plot design was used with cultivars as main plots and K

levels as subplots. The plot size was 6 × 3 m and the treatments were replicated three times. Whole plant tops were sampled at flowering to determine dry matter and K uptake in the third and fourth year. Plant material was dried to constant weight and milled. Ground material was digested with a 2:1 mixture of HNO<sub>3</sub> and HClO<sub>4</sub>. The K concentration in the digest was determined by atomic absorption spectroscopy.

After harvesting each crop, soil samples were taken from each plot at 0–20, 20–40, 40–60 and 60–80 cm depth intervals to evaluate soil K movement. Data were analyzed by analysis of variance and orthogonal contrasts for linear and quadratic responses to K application rates, plant K concentrations and soil extractable K.

## Results and discussion

Application of K significantly affected grain yield and dry matter production of upland rice cultivars (Table 2). There was a significant difference among cultivars in grain yield for three of the five years. Cultivar × K interactions for grain yield were significant during four cropping seasons.

The effect of K fertilization on grain yield is shown in Table 3. Potassium fertilization generally increased grain yield but the effect varied from cultivar to cultivar and year to year. This variation may be attributed to both weather and disease. In central Brazil, two to three week droughts are very common during the growth of upland rice [4]. During the first cropping season, there was a twenty day drought. The drought started six days

Table 2. F-values for analysis of variance of grain yield, dry matter<sup>a</sup>, K-concentration<sup>b</sup> and K-uptake<sup>c</sup> by upland rice and K-extracted from the soil

Source of variance	Grain yield	Dry matter	K-concentration	K-uptake	Soil extractable K
<i>1st crop</i>					
Cultivar (cv)	162.46**				0.15 NS
K	21.14**				13.48**
cv × K	6.16**				1.65 NS
<i>2nd crop</i>					
Cultivar (cv)	11.72*				4.42 NS
K	5.16**				59.12**
cv × K	3.11**				1.11 NS
<i>3rd crop</i>					
Cultivar (cv)	1.67 NS	1.25 NS	0.71 NS	0.16 NS	0.04 NS
K	3.07*	11.45**	24.03**	27.65**	107.45**
cv × K	0.46 NS	1.30 NS	3.11**	1.57 NS	0.52 NS
<i>4th crop</i>					
Cultivar (cv)	20.75**	2.41 NS	1.08 NS	0.42 NS	2.05 NS
K	14.66**	19.48**	80.58**	38.03**	78.74**
cv × K	59.02**	8.65**	7.44**	6.25**	0.68 NS
<i>5th crop</i>					
Cultivar (cv)	0.63 NS				0.17 NS
K	4.46**				89.01**
cv × K	3.81**				0.61 NS

\*,\*\* Significant at the 5 and 1% probability levels, respectively. NS = Not significant.

<sup>a</sup> Dry matter at flowering was measured for the 3rd and 4th crops and therefore K-analysis in the plant tissue was only done for these two crops.

<sup>b</sup> K-conc. = K-content per unit dry matter.

<sup>c</sup> K-uptake = K-conc. × dry matter.

Table 3. Effect of K fertilizer application on grain yield of upland rice

K applied	1st crop			2nd crop			3rd crop			4th crop			5th crop		
	C <sub>1</sub> <sup>b</sup>	C <sub>2</sub>	C <sub>3</sub>	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>
kg K ha <sup>-1</sup>	kg ha <sup>-1</sup>														
0	957	1917	1097	1740	580	1627	622	625	563	783	683	1230	2277	2118	2050
42 (25) <sup>a</sup>	931	2192	1115	1963	588	1817	708	650	647	1200	653	1510	2403	2302	2183
84 (50)	843	2183	1315	1883	548	1967	700	647	662	1253	730	1663	2285	2352	2245
126 (75)	1053	2561	1373	1880	748	1907	716	657	683	1093	737	1520	2317	2368	2482
168 (100)	867	2133	1266	1783	633	2023	743	640	675	1057	750	1583	2332	2010	2447
Linear	NS	**	**	NS	NS	**	*	NS	*	**	*	**	NS	NS	**
Quadratic	NS	**	*	*	NS	NS	NS	NS	NS	**	NS	**	NS	**	NS
Physiol. Maturity (days)	112	135	112	113	138	113	125	136	115	115	132	111	102	109	102

\*,\*\* Significant at the 5 and 1% probability levels, respectively. NS = Not significant.

<sup>a</sup> Values in parentheses represent K band application rates in the fourth and fifth growing season.

<sup>b</sup> Upland rice cultivars used: crops 1–3, C<sub>1</sub> = Dourado Precoco, C<sub>2</sub> = IAC 47, C<sub>3</sub> = IAC 164; Crop 4, C<sub>1</sub> = CNA 108, C<sub>2</sub> = IAC 47, C<sub>3</sub> = IAC 164; Crop 5, C<sub>1</sub> = CNA 4166, C<sub>2</sub> = CNA 4476, C<sub>3</sub> = CNA 418.

Table 4. Effect of K fertilizer application on concentration and uptake of K by upland rice and dry matter production

K applied kg K ha <sup>-1</sup>	3rd crop			4th crop					
	Dourado Precoce			IAC 164			IAC 47		
	Conc. <sup>a</sup> (g kg <sup>-1</sup> )	Uptake <sup>b</sup> (kg ha <sup>-1</sup> )		Conc. (g kg <sup>-1</sup> )	Uptake (kg ha <sup>-1</sup> )		Conc. (g kg <sup>-1</sup> )	Uptake (kg ha <sup>-1</sup> )	
0	18.5	46		18.0	48		15.0	54	
42 (25) <sup>c</sup>	16.3	45		20.2	60		17.0	69	
84 (50)	20.3	65		20.7	65		20.0	80	
126 (75)	20.8	70		21.0	64		21.0	95	
168 (100)	24.0	75		22.8	75		18.3	70	
Linear	**	**		**	**		**	**	
Quadratic	*	NS		NS	NS		**	**	
<i>Dry matter (kg ha<sup>-1</sup>)</i>									
0	2615		2401	2680		3531	4232		3891
42 (25)	2762		2893	3027		3998	4704		4976
84 (50)	3089		2828	3199		4043	5490		4234
126 (75)	3318		3115	3009		4506	4953		5063
168 (100)	3140		2905	3244		3832	4663		5447
Linear	**	**	**	**	**	*	*	*	**
Quadratic	*	*	*	NS	NS	**	**	**	NS

\*\* Significant at the 5 and 1% probability levels, respectively. NS = Not significant.

<sup>a</sup> K-conc. = K-content per unit dry matter.<sup>b</sup> K-uptake = K. conc. × dry matter.<sup>c</sup> Values in parentheses represent K band application rates in the fourth and fifth growing seasons.

Table 5. Regression equations relating grain yield and dry matter production to K application rate and soil extractable K

Crop	Cultivar	Regression	R <sup>2</sup>	K level associated with maximum yield <sup>b</sup>
<i>K applied<sup>a</sup></i>				
1st	IAC 47	Grain yield = $1891 + 7.42K - 0.029 K^2$	0.64	105 kg K ha <sup>-1</sup>
	IAC 164	Grain yield = $1058 + 3.44K - 0.011 K^2$	0.78	127 kg K ha <sup>-1</sup>
2nd	Dourado Precoce	Grain yield = $1769 + 3.23K - 0.016 K^2$	0.72	83 kg K ha <sup>-1</sup>
3rd	Dourado Precoce	Dry matter = $2547 + 8.51K - 0.026 K^2$	0.89	134 kg K ha <sup>-1</sup>
	IAC 47	Dry matter = $2433 + 8.46K - 0.030 K^2$	0.84	117 kg K ha <sup>-1</sup>
4th	CNA 108	Grain yield = $829 + 12.13K - 0.089 K^2$	0.82	56 kg K ha <sup>-1</sup>
	IAC 164	Grain yield = $1254 + 9.34K - 0.058 K^2$	0.84	67 kg K ha <sup>-1</sup>
	CNA 108	Dry matter = $3493 + 21.45K - 0.148 K^2$	0.74	61 kg K ha <sup>-1</sup>
	IAC 47	Dry matter = $4179 + 30.82K - 0.226 K^2$	0.83	56 kg K ha <sup>-1</sup>
5th	CNA 4476	Grain yield = $2100 + 10.18K - 0.089 K^2$	0.91	47 kg K ha <sup>-1</sup>
<i>Soil extractable K</i>				
1st	IAC 47	Grain yield = $893 + 67.81K - 0.85 K^2$	0.64	40 mg K kg <sup>-1</sup>
	IAC 164	Grain yield = $-1405 + 144.41K - 1.91 K^2$	0.71	38 mg K kg <sup>-1</sup>
2nd	Dourado Precoce	Grain yield = $-1088 + 17.61K - 2.44 K^2$	0.48	35 mg K kg <sup>-1</sup>
3rd	Dourado Precoce	Dry matter = $11775 - 451.19K + 5.40 K^2$	0.60	42 mg K kg <sup>-1</sup>
	IAC 47	Dry matter = $-299 + 123.11K - 1.14 K^2$	0.75	54 mg K kg <sup>-1</sup>
4th	CNA 108	Grain yield = $-2150 + 198.04K - 2.93 K^2$	0.91	34 mg K kg <sup>-1</sup>
	IAC 164	Grain yield = $-1426 + 151.08K - 1.89 K^2$	0.89	40 mg K kg <sup>-1</sup>
	CNA 108	Dry matter = $-1246 + 320.49K - 4.74 K^2$	0.64	34 mg K kg <sup>-1</sup>
	IAC 47	Dry matter = $-5220 + 610.80K - 8.80 K^2$	0.84	35 mg K kg <sup>-1</sup>
5th	CNA 4476	Grain yield = $2669 + 213.46K - 2.25 K^2$	0.42	47 mg K kg <sup>-1</sup>

<sup>a</sup> The regression equations were calculated using fertilizer application rates expressed as K<sub>2</sub>O. All other K values in the manuscript are expressed as elemental K.

<sup>b</sup> Calculated from the quadratic regression equation for a given cropping year and cultivar.

after panicle initiation and ended four days before flowering for Dourado Precoce and IAC 164 and covered the 20 days prior to panicle initiation for IAC 47. In the second year there was a 13 day drought. This corresponded to the maturity growth stage of Dourado Precoce and IAC 164 and around the flowering stage in IAC 47. The reproductive growth stage of upland rice is more sensitive to drought than the vegetative and maturity growth stages [3]. Therefore, during the first growing season Dourado Precoce and IAC 164 produced significantly lower grain yields than IAC 47. In the second growing season IAC 47 was in a growth stage that was more vulnerable to drought conditions. In the third year, all three cultivars suffered from panicle neck blast due to a different growth cycle and therefore produced lower grain yields as compared to the first two growing seasons. In the last year of the study there was no drought and blast resistant cultivars were planted. Grain yields

of all three cultivars were considerably higher than those obtained during the first four growing seasons.

Potassium concentrations and uptake in the shoots increased with increasing level of K fertilizer (Table 4). There were differences in shoot K concentrations and uptake among cultivars. This may be related to differences in dry matter production (Table 4). The cultivars which produced higher dry matter yields had lower concentrations of K in their tops. This was due to a dilution effect.

Quadratic regression equations relating grain yield and dry matter to K application rates are given in Table 5. Quadratic equations are only given for cultivars which demonstrated significant quadratic constraints for grain yield and dry matter (Tables 3 and 4).

Band application of K may allow maximum upland rice grain yields to be obtained at lower K rates than broadcast application. The application

Table 6. Simple correlation coefficients between grain yield, dry matter, K-concentration<sup>a</sup>, K-uptake<sup>b</sup> and soil extractable K

Variables	Grain yield	Dry matter	K-concentration	K-uptake	Soil extractable K
Grain yield	1.00				
Dry matter	0.26**	1.00			
K-conc.	0.15*	0.28**	1.00		
K-uptake	0.29**	0.81**	0.77**	1.00	
Soil extractable K	0.15*	0.21**	0.28**	0.29**	1.00

\*,\*\* Significant at the 5 and 1% probability levels, respectively.

<sup>a</sup> K-conc. = K-content per unit dry matter.

<sup>b</sup> K-uptake = K-conc.  $\times$  dry matter.

method was changed from broadcast to banding and K application rates were lowered after the first three years. Potassium rates for maximum grain yields varied from 83 to 127 kg K ha<sup>-1</sup> using broadcast application of K during the first and second growing seasons. Maximum dry matter production was obtained with the broadcast application of 117

to 134 kg K ha<sup>-1</sup>. When K was applied in the band in the fourth and fifth years, maximum grain yields were obtained at 47 to 67 kg K ha<sup>-1</sup>. The cultivar CNA 108 produced maximum dry matter with the application of 61 kg K ha<sup>-1</sup> in the band. Maximum yields were obtained at lower K application rates for band application of K compared to broadcast

Table 7. Influence of K fertilizer application rates on soil extractable K at different soil depths

K applied	Soil depth	After harvest				
		1st crop	2nd crop	3rd crop	4th crop	5th crop
kg K ha <sup>-1</sup>	cm	mg kg <sup>-1</sup>				
0	0-20	30	26	31	24	35
	20-40	19	20	22	20	19
	40-60	16	15	15	13	14
	60-80	14	14	13	11	10
42 (25) <sup>a</sup>	0-20	31	29	45	34	45
	20-40	21	24	27	26	25
	40-60	17	18	17	17	15
	60-80	18	16	16	14	12
84 (50)	0-20	34	31	50	38	53
	20-40	24	28	33	32	34
	40-60	20	18	21	20	18
	60-80	19	19	21	15	14
126 (75)	0-20	37	34	55	41	58
	20-40	29	37	40	37	42
	40-60	24	23	25	23	22
	60-80	23	24	25	18	17
168 (100)	0-20	43	40	59	43	63
	20-40	29	42	46	41	50
	40-60	23	25	30	27	28
	60-80	24	28	30	20	19
Statistical sig.						
K levels (K)		**	**	**	**	**
Depth (D)		**	**	**	**	**
K $\times$ D		NS	**	**	**	**

\*,\*\* Significant at the 5 and 1% probability levels, respectively. NS = Not significant.

<sup>a</sup> Values in parenthesis represent K band application rates in the fourth and fifth growing seasons.

application. These results, however, cannot be interpreted as an endorsement of band over broadcast application of K. Previous broadcast K, favorable weather and blast resistant cultivars may have contributed to the higher yields with K banding in the fourth and fifth growing seasons. Even the zero K treatments showed yield improvements in year five compared to the first four growing seasons (Table 3).

Simple correlation coefficients between grain yield, dry matter and plant and soil K status are shown in Table 6. Correlations between grain yield, dry matter, plant K concentration, plant K uptake and soil extractable K were significant but the highest correlation was between dry matter and K uptake in the shoots.

Extractable K values were determined in the soil profile after each harvest (Table 7). Significant differences ( $P < 0.01$ ) in extractable K existed with K application rate and depth. Extractable K increased with K application rate and decreased with soil depth (Table 7). Applied K increased extractable K in both the surface and the subsoil. Leaching of K to lower depths was especially noticeable at the higher K rates. At the highest K rates, soil K-levels were 71, 100, 131, 82, and 90% higher in the 60–80 cm soil depth at the end of each growing season, respectively, when compared to the control treatment.

Quadratic regression equations relating grain yield and dry matter production to soil test K levels are shown in Table 5. The extractable K levels associated with maximum grain yield varied from 34 to 47 mg K kg<sup>-1</sup> depending on cultivar and years of cropping. Similarly, extractable K associated with maximum dry matter production varied from 34 to 54 mg K kg<sup>-1</sup>.

## Summary

Upland rice yields can be significantly increased

with K fertilization in the Cerrado region of Brazil. Maximum yields were obtained at lower K application rates for band application of K compared to broadcast application. Soil extractable K decreased with increasing soil depth and movement of K to lower depths was observed especially at high K application rates. Drought and panicle neck blast are the most important factors which limit upland rice yield response to K fertilization. The negative effects of these two yield limiting factors can be minimized by using drought and blast resistant cultivars and adopting appropriate cultural practices.

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